Before the

FEDERAL COMMUNICATIONS COMMISSION

Washington, DC 20554

In the Matter of	)	
	)	
Tyvak Nano-Satellite Systems Inc.	)	
	)	
Application for Authority for Operation of	)	File No. 0589-EX-ST-2022
an Experimental Non-Geostationary	)	
Low Earth Orbit Satellite	)	

NARRATIVE EXHIBIT

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NARRATIVE EXHIBIT

Tyvak Nano-Satellite Systems Inc. ("Tyvak") provides nano-satellite, micro-satellite, and CubeSat space vehicle products and services that target advanced state-of-the-art capabilities for government and commercial customers to support operationally and scientifically relevant missions. With this Application, Tyvak requests 6 month special temporary authority for operation of an experimental Sun-Synchronous non-geostationary ("NGSO") low earth orbit ("LEO") CubeSat satellite referred to as Tyvak-125.[1] The Tyvak-0125 satellite is currently scheduled to be launched on June 1, 2022 under authority provided by the United States government. This application seeks experimental authority from the Commission to operate the satellites using earth stations located within the United States.

The RF communications links for the satellites will use the 400 MHz UHF band for two-way telemetry monitoring, tracking, and command ("TT&C") transmissions and the 2 - 2.2 GHz S-band for two-way TT&C and data downlink. Authority is also requested herein for the use of multiple earth stations in the United States to communication with the Tyvak-0125 satellites.

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[1] Tyvak currently holds experimental authorization from the Commission for similar CubeSats that are currently in operation. *See* ELS File No. 0987-EX-CN-2018 (Call Sign WK2XAJ) (granted April 27, 2020); 0527-EX-CN-2021 (Call Sign WJ2XZG) (granted Sept. 10, 2021): 0526-EX-CN-2021 (Call Sign WJ2XZK) (granted Sept. 10, 2021).

I. NARRATIVE INFORMATION

Government Contract Information

Government Contract NNA17BF41C states Tyvak Nano-Satellite Systems LLC as the contractor for NASA's Ames Research Center. This contract was awarded 01/09/2017 with a completion date of 12/31/2022.

Tyvak is seeking authority to operate its Tyvak-0125 satellite in support of the Pathfinder Technology Demonstrator (PTD) series. PTD-3 is a NASA payload flying on a non-government commercial cubesat. PTD-3 comprises one space vehicle in a sun-synchronous 525km circular orbit at an inclination of 97.5 degrees. This demonstrator will benefit future missions by demonstrating the operation of new subsystem technologies in orbit. These may include spacecraft systems that provide the capability to maneuver small science platforms and send small spacecraft to deep space, novel technologies to stabilize spacecraft, and a laser communication system that will greatly increase the amount of data that can be transmitted from the spacecraft to the ground. PTD-3 will demonstrate the last of these described payloads. By flight qualifying these subsystems, NASA benefits by having access to low-cost, highly capable science and technology platforms that can operate from the near-Earth to the deep space environment. The PTD-3 payload is the TeraByte InfraRed Delivery (TBIRD) large-volume direct-to-Earth data transfer system, designed and developed by the Massachusetts Institute of Technology (MIT) Lincoln Laboratory (LL). TBIRD will use its camera sensors to generate camera data on orbit and subsequently downlink that data to Earth-based optical ground terminals through its laser communications (Lasercom) system. This instrument is not expected to communicate (Tx or Rx) in any RF frequency range.

The successful completion of the above-described research project requires the use of the communications facilities identified in this application. The use of RF communications equipment both on the satellite and at an earth station are necessary to monitor and control the satellite, direct its operations and to downlink the resulting data for collection and analysis. Of particular importance is the use of off-the-shelf radio equipment that is designed to be compatible with the uniform payload form factor requirements of Cubesat spacecraft and has been demonstrated to be available and reliable for use in space-based communications. The frequencies identified in this experimental license application involving UHF frequencies in the range of 400 MHz and S-band frequencies in the 2.2 GHz range satisfy both of these requirements.

Justification of the need for a 6 month experimental license term

As noted previously, the Tyvak-0125 satellite will launch on June 1, 2022. To satisfy NASA's mission objectives, the mission will be 6 months from launch with a maximum 2year expected operational lifetime. Following that mission period, Tyvak will implement operational measures using additional drag to expedite the reentry of the satellite and its incineration in the atmosphere.

Transmitting Equipment to be Installed, Including Manufacturer, Model Number and Whether the Equipment is Experimental in Nature

The satellites employs frequencies in the 400 MHz UHF range and the 2.2 GHz S-band range for telemetry, command and control ("TT&C") operations. The following graphic provides an overview of the transmitting and receiving components of each element. The specific model numbers are subject to change based on product availability and system upgrades.

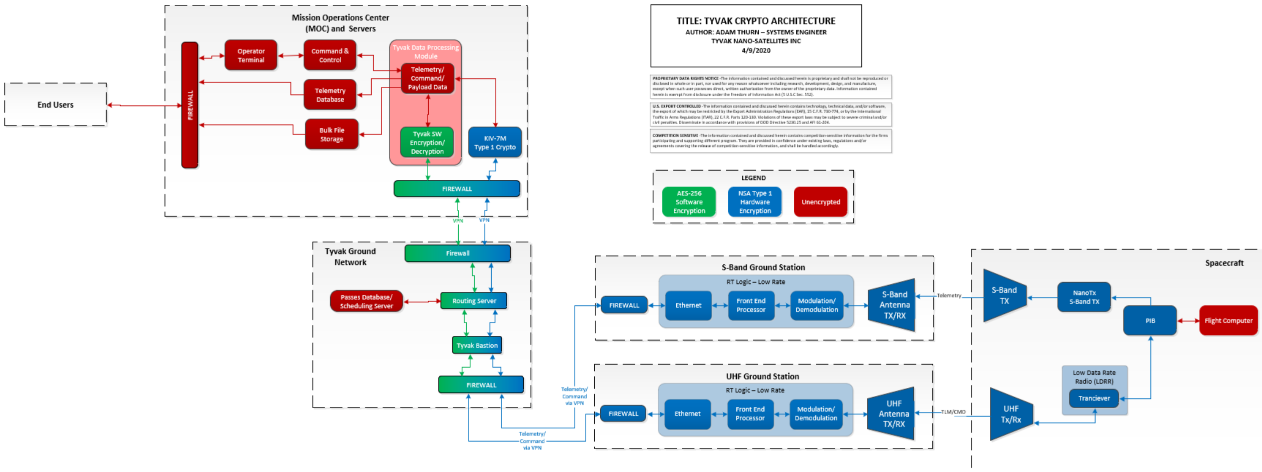

Figure 1: CubeSat System Communications Components

The transmitting components aboard the CubeSat are controlled by a dedicated on-board processor, which processes data for transmission, sends and receives data from the modem, and activates the appropriate radio systems depending on the state of operations. The vehicle possesses a UHF system for vehicle command and telemetry retrieval and an S-band system.

The TT&C communications system uses a Tyvak-developed UHF radio derived from commercially available UHF communications systems. The radio operates at a 19.2 kbps rate using GMSK modulation. The UHF system has an RF output power of 1 watt and uses a custom designed half-wave dipole antenna. The identical radio was previously used on the Tyvak-0129 satellite and has operated without problem.

The payload S-band communications system operates at 2 watts using an off-the-shelf Quasonix NanoTX radio and patch antenna developed by Haigh-Farr for transmission. Similar to the UHF radio, the S-band radio has previously been used on-orbit several times without any problems including on Geostare SV2.

S-band transmissions are completed with blind downlinks and the vehicle does not transmit S-band unless commanded by the ground to enable based on the ground station's GPS location or via absolute time. The S-band radio supports a 2 Mbps BPSK data rate using a transmit power of 2 watts. The antenna is RHCP with a gain greater than 5dBic at the boresight with a VSWR < 2:1.

The UHF band earth station facilities are located in San Diego, California and Fairbanks, Alaska and each consists of a Yagi antenna array manufactured by M2 Systems, model number 400CP30. The S-band ground earth station is located in Petaluma, California and consists of a 3.7 meter antenna manufactured by Seatel as model number 3700. The antenna is located on the roof of an access-controlled building in Petaluma, California. Tyvak will control the earth station by remotely from its Mission Operations Center ("MOC") in Irvine, California.

Is the Equipment Listed in Item 10 Capable of Station Identification Pursuant to Section 5.115

To support the operational security of the Tyvak-0125 satellite, neither the satellites nor the associated ground facilities are designed to transmit station identification signals for the spacecraft.

Antenna Registration Form; Operation of Directional Antenna

Tyvak-0125 is a low earth orbit ("LEO") satellite in a 525 km circular orbit with an inclination of 97.5 degrees and an orbit period of approximately 96 minutes. The satellite will pass over the Earth station roughly one to twelve times per day depending on its location with an average access time of five to nine minutes for each earth station location. The UHF earth station will use a computer-controlled tracking antenna to point the earth station's antenna in the direction of the moving satellites. The antenna has a maximum gain of +20.2dBi along the bore-sight of the antenna and a half-power beam-width of approximately 22 degrees. The antenna array uses four off-the-shelf, Yagi-type antennae developed by M2 Antenna Systems, Inc.

Tyvak-0125 is a NGSO satellite, thus the range of antenna azimuth and elevation will vary based on the relative motion of the satellite with respect to the ground station. It will also differ for each satellite pass. The earth station will only transmit above the horizon. Consequently, the range of antenna elevation angles for all satellite passes will be between 0 and 180 degrees. The azimuth can vary between 0 degrees and 360 degrees.

II. RELEVANT INFORMATION ADDRESSED IN SECTION 25.114 OF THE COMMISSION'S RULES

Radio Frequency Plan

UHF Communications System

The UHF communications system for the Tyvak-0125 satellite operates using half-duplex communications within a center frequency of 401.205 MHz for bi-directional telemetry, tracking, and commanding. (*i.e.*, earth-to-space & space-to-earth) Tyvak-0125 is performing earth exploration payload technology demonstrations and thus the use/categorization of the communications as an earth exploration satellite is justified in both the US and international allocation for the 399-400 MHz earth-to-space range. The space vehicle UHF communication system is half-duplex and, as such, the similar UHF center frequency for both telecommand and telemetry poses no operational concern.

Space-to-Earth and Earth-to-Space UHF Communications

The Tyvak-0125 satellite has been designed to include several precautions to prevent harmful interference to other services from space-to-earth transmissions. First, as noted above, space-to-earth satellite transmissions will be controlled from the Earth station and the spacecraft will not transmit until it receives a request from the earth station.

Second, the satellite uplink and downlink will use the same 22 kHz bandwidth in half-duplex mode to send digital data using standard GMSK modulation with maximum data rates up to 19,200 baud. The communications parameters for the UHFcommunications system for the space-to-earth and earth-to-space links are shown in the following table.

Specification	UHF-Band Down
Center Frequency	401.205 MHz
Bandwidth	0.022 MHz
RF Output	2 W
ERP	1.93 W
Antenna Gain	2 dBi
Manufacturer	Tyvak
Bit Rate	19.2 kbps
Symbol Rate	19.2 ksps
Modulation	GMSK
Encoding	AX.25
Sample Designator	22K0F1D

Table 1: Tyvak-0125 UHF Communications Space-to-Ground Parameters

Specification	UHF-Band Up
Center Frequency	401.205 MHz
Bandwidth	0.022 MHz
RF Output	200 W
ERP	6400.1 W
Antenna Gain	17.2 dBi
Manufacturer	Tyvak

Bit Rate	19.2 kbps
Symbol Rate	19.2 ksps
Modulation	GMSK
Encoding	AX.25
Sample Designator	22K0F1D

Table 2: Tyvak Earth Station UHF Communications Parameters

Earth Station	Frequency Range	Geographic Coordinates
San Diego, CA, USA	UHF	32.897°Lat, -117.201°Long
Fairbanks, AK, USA	UHF	64.855°Lat, -147.686°Long

Table 3: Tyvak Earth Stations UHF

S-Band Communications System

The spacecraft's S-band communications system will operate using simplex communications within the 2050-2215 MHz frequency band to command the experimental sensors and to downlink recorded payload data to Tyvak-affiliated S-band Earth stations. The S-band system operates in the space-to-earth direction using a center frequency of 2212.9 MHz. The S-band system operates in the earth-to-space direction using a center frequency of 2072.5 MHz. Transmissions between the satellite and the ground will be with an earth station on the rooftop of an access controlled building. Tyvak will control the earth station from its MOC in Irvine, California. The communications parameters for the S-band communications system for the space-to-earth and inter-satellite links are shown in the following tables.

Specification	S-Band Downlink
Center Frequency	2212.9 MHz
Bandwidth	2.867 MHz
RF Output	2 W
ERP	6.11 W
Antenna Gain	7
Manufacturer	Quasonix
Bit Rate	2048 kbps

Symbol Rate	2048 ksps
Modulation	BPSK
Encoding	CCSDS
Sample Designator	2M87G1D

Table 4: Tyvak-0125 S-Band Space-to-Ground Communications Parameters

Specification	S-Band Uplink
Center Frequency	2072.5 MHz
Bandwidth	0.175 MHz
RF Output	160 W
ERP	245 kW
Antenna Gain	34 dBi
Manufacturer	Tyvak
Bit Rate	125 kbps
Symbol Rate	125 ksps
Modulation	BPSK
Encoding	CCSDS
Sample Designator	175KG1D

Table 5: Tyvak Earth Station S-band Communications Parameters

Earth Station	Frequency Range	Geographic Coordinates
Petaluma, California	S-Band	38°16'27.2"N 122°39'48.5"W

Table 6: Tyvak Earth Stations S-Band

The Tyvak-0125 CubeSat will communicate with the UHF ground stations and S-band ground stations only when they are within line-of-sight of the earth stations and have received a communication from the earth station directing the spacecraft to initiate transmissions. Consequently, the spacecraft will utilize the 400 MHz and 2.2 GHz bands only when in contact with specified earth stations and potentially conflicting uses of the band in other regions of the world are not relevant to this application.

Spectrum Sharing and Interference Mitigation Techniques

The S-band communications system employs multiple design considerations that make it highly unlikely that harmful interference could result to any other satellite network. These include low-altitude, near-polar orbits and the use of short-duration, narrow bandwidth transmissions.

Sharing With Low Earth Orbit Satellite Networks: The Tyvak network is highly unlikely to cause unacceptable interference to other low-altitude satellite networks. First, transmissions from Tyvak spacecraft will be infrequent and of short duration, triggered only by affirmative command from the Tyvak MOC. Second, conjunction events in which a Tyvak satellite and another low-altitude satellite are relatively close to each other will occur very infrequently. When such rare conjunction events do occur, there will still be no potential for interference unless both satellite systems are transmitting at the same time, which would only happen when a Tyvak earth station is in close geographic proximity to the earth station of another network. Given the international allocation for EESS across the entire 2050-2215 MHz frequency band, other NGSO satellites operating in proximity to any Tyvak satellites are highly likely to follow similar interference mitigation procedures as those outlined above, resulting in high confidence that Tyvak operations will not cause unacceptable interference to other low-altitude satellite networks.

Sharing With Geostationary Satellite Networks: The Tyvak network is highly unlikely to cause unacceptable interference with geostationary ("GSO") or other high-altitude satellite networks. The 2050-2215 MHz frequency band is not significantly used by GSO satellite networks. With respect to earth-to-space transmissions, the Tyvak transmissions will operate at relatively low power and therefore will not result in harmful interference to other space systems. With respect to space-to-Earth transmissions from GSO spacecraft using the 2050-2215 MHz frequency band, these will be protected from harmful interference from the Tyvak satellite transmissions in the same manner as Tyvak will protect space-to-Earth transmissions from low Earth orbit NGSO networks, as discussed above.

Sharing With Fixed Service Networks: The Tyvak network operates in compliance with the ITU power limits specified to protect the Fixed Service operating in the 2050-2215 MHz frequency band. Table 21-4 of ITU Radio Regulation number 21.16 specifies the following PFD limits at the Earth's surface for emissions from EESS space stations operating in the 2050-2215 MHz frequency band for all conditions and for all methods of modulation.

Frequency band	**Service***	**Limit in dB(W/m^2) for angles of arrival (δ) above the horizontal plane**			**Reference bandwidth**
		0°-5°	**5°-25°**	**25°-90°**	
2 200-2 300 MHz	Earth exploration-satellite (space-to-Earth)	-154	$-154 + 0.5(\delta - 5)$	-144	4 kHz

Table 8: ITU Radio Regulation 21.16, Table 21-4

When calculated at the minimum anticipated operating orbital altitude for Tyvak-0125 of 525 kilometers, the PFD levels at the Earth's surface produced by the Tyvak satellite data and telemetry downlink transmissions will comply with these limits.

Orbital Location

Tyvak-0125 operates in LEO with the orbit parameters shown in Table 8. The satellite has an orbit period of approximately 96 minutes with typical ground access times of five to seven minutes per pass. The orbit parameters are presented in the following table:

Spacecraft	Parameter	Units	Value
Tyvak-0125	Orbit Period	Hrs	1.57 hrs
	Orbit Altitude	Km	525 km (circular)
	Inclination	Deg	97.5 degrees

Table 9: CubeSat Orbit Parameters

Physical Characteristics of Satellite

The Tyvak-0125 space vehicles are a nano-class (< 14 kg) satellite, in which each element conforms to the CubeSat standard. These spacecraft have identical physical characteristics. CubeSats can be designed in different sizes as long as they aremultiples of the basic CubeSat standard unit, which is 10×10×10 centimeters, generally referred to as a 1U CubeSat, meaning one unit in size. Tyvak-0125 is 6U in size, which means each CubeSat will have the dimensions of approximately 36×25×10 centimeters or 36 x 25 x 10 cm. The CubeSat dispenser limits the total vehicle mass of a 6U CubeSat to less than 14 kg respectively. The Tyvak-0125 vehicle has been designed primarily as a single-string system using commercial off-the-shelf ("COTS") parts with an on-orbit lifetime of approximately two years. The mass budget is provided in the following table:

Component / Subsystem	Mass [kg] 6U
Spacecraft	12

Table 10: Spacecraft Mass Budget (1 spacecraft)

For power generation, Tyvak-0125 are equipped with two deployable solar arrays. Because of the short operational lifetime of the satellite, the difference between the beginning-of-life ("BOL") and end-of-life ("EOL") power generation is negligible. To permit operations during eclipse, energy is stored on-board using Lithium- ion batteries, with power distributed to subsystems and components through the electrical power subsystem. The EOL power budget is provided in the following table by phase of operations:

Mission Phase	Bus Totals (W)	Phase Totals (W)
FIRST_BOOT	1.01	1.01
CDH_ONLY	5.63	6.35
TUMBLE_MAG	4.62	5.34
SAFE_MODE	4.62	8.18
SUNPOINTING	4.14	7.70
PAYLOAD_HOLD	0.85	3.70
PAYLOAD_BURN	5.29	14.50
PAYLOAD_RPOD	5.29	13.96
PAYLOAD_NEAR_FIELD	5.29	15.88
PAYLOAD_FAR_FIELD	4.62	8.18
DOCKED_SLAVE	2.01	2.01
DOCKED_MASTER	4.14	4.86

Table 11: Power Budget per Space Vehicle

Operational Schedule

The Tyvak-0125 satellites will be launched on June 1, 2022. The project timeline and major milestones for the operation of the Tyvak-0125 satellite are provided in the following table.

Milestone	**Date**	**Notes**
Launch	June 1, 2022	ToL + 0
Decommissioning	Dec 31 2022	ToL + 6 Months

Re-entry	May 2032	ToL + 10 years

Table 12: Tyvak-0125 Major Milestones

Public Interest Considerations

The grant of this application would greatly serve the public interest. As indicated above, Tyvak is operating the satellite to validate the technologies that are needed to support rendezvous, proximity operations, docking, servicing, and formation flight by utilizing a pair of identical nano-satellites and leveraging the inherent relative low costs of their vehicle manufacture and launch capabilities. It will also validate use of a completely new set of low power miniature components and software approach. Tyvak seeks Commission authority through this experimental license application to downlink the imaging data using an U.S.-based earth station maintained at an access-controlled facility in the United States in order to heighten the security of these downlink transmissions and their assured collection and retention by Tyvak. This added level of security for the experimental imaging data would clearly serve the public interest.

Predicted Spacecraft Antenna Gain Contours

The spacecraft UHF antenna is a half wavelength L-dipole antenna, which is essentially omni-directional when mounted on the corner of a CubeSat structure. A simulation of the antenna design is shown in Figure 2.

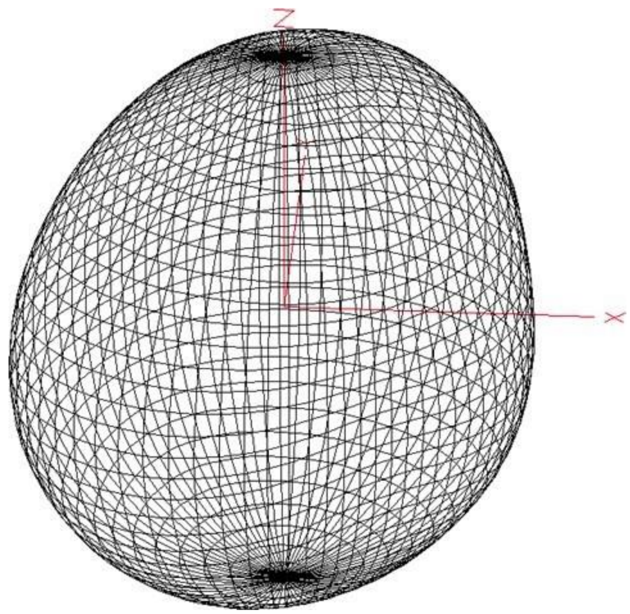

Figure 2: Tyvak-XXXX L-Dipole UHF Antenna Gain Plot

The spacecraft S-band antennas are microstrip patch antennas possessing a maximum gainperpendicular to the surface normal to the patch. A representative antenna gain pattern cut is provided below for the S-band patch.

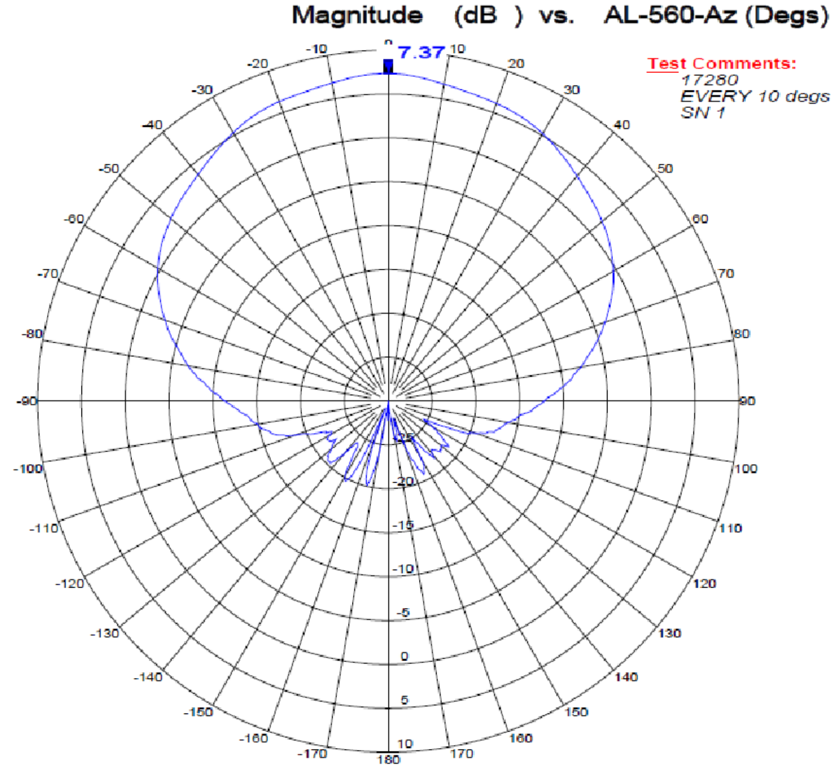

Figure 3: CubeSat S-band Antenna Gain Plot